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Metasurfaces for Engineering Beam Reflections

S. Kosulnikov[1], **X. Wang**[2], **Francisco Cuesta**[1], **Y. Li**[1], **and S. Tretyakov**[1]

[1]Department of Electronics and Nanoengineering, Aalto University, Espoo, Finland
[2]Institute of Nanotechnology, Karlsruhe Institute of Technology, Germany
sergei.tretyakov @ aalto.fi

Abstract – **In this presentation we will review our recent works on designs and testings of effective anomalous reflectors and beam splitters. First, we will make a comparative overview of known methods to design stationary and reconfigurable metasurfaces for shaping reflected waves. Next, we will present our recently developed approach based on optimization of step-wise homogeneous impedance sheets. We will show examples of practical designs and experimental results in the millimeter-wave band. Furthermore, we will discuss reflection and scattering from finite-size metasurfaces mounted an walls and show a possiblity to change reflections from the illuminated part of the uniform wall by engineering interference with the waves scattered by the metasurface.**

I. METHODS TO DESIGN METASURFACES FOR REFLECTION CONTROL

In order to enable any anomalous reflection (when the reflection angle is not equal to the angle of incidence), the surface must be inhomogeneous at the wavelength scale. Indeed, in reflections from uniform surfaces the conservation of momentum does not allow changing the tangential component of the wavevector. There are two fundamentally different classes of anomalous reflectors: periodical metasurfaces or metagratings and aperiodical reflectarrays [1]. The simplest, classical approach to design these devices is the locally periodical approximation (basically the same as physical optics), but this approach may lead to significant parasitic scattering.

Design of periodical reflectors and diffraction gratings is well studied in the literature. There exist several methods, all allowing realization of anomalous reflectors where parasitic scattering is effectively suppressed. In all of these methods the main challenge is to engineer excitation of evanescent modes (surface waves) in order to suppress excitations of unwanted propagating Floquet harmonics. Let us briefly list the main known approaches [1]:

1. Model the reflector as a boundary defined by its surface (input) impedance. Allowing excitation of surface-bound modes, design the surface impedance profile $Z_s(x)$ so that only the desired reflected propagating mode exists, enforcing $\mathrm{Re}[Z_s(x)] = 0$ as an additional condition. Importantly, actual realizations of the optimized surface impedance still require the locally periodical approximation, possibly leading to performance degradation.

2. Start from a certain topology (usually a patterned metal sheet on a grounded dielectric substrate) and optimize the evanescent fields so that the effective sheet impedance of the thin patterned metal layer is lossless at every point. The locally periodical approximation is also used in this method, but only for the design of the reactive sheet, instead of the whole metasurface body.

3. Considering arrays of thin metal strips on a grounded substrate and using the periodic Green function for a grounded dielectric substrate, find the loading impedances of strips analytically. This approach is a variation of the metagrating design method.

4. Design the current distribution so that only the desired plane wave is created by direct optimization of the metasurface structure (not relying on sheet/surface impedance boundary conditions and not requiring reactive input impedance at any surface, except the ground plane).

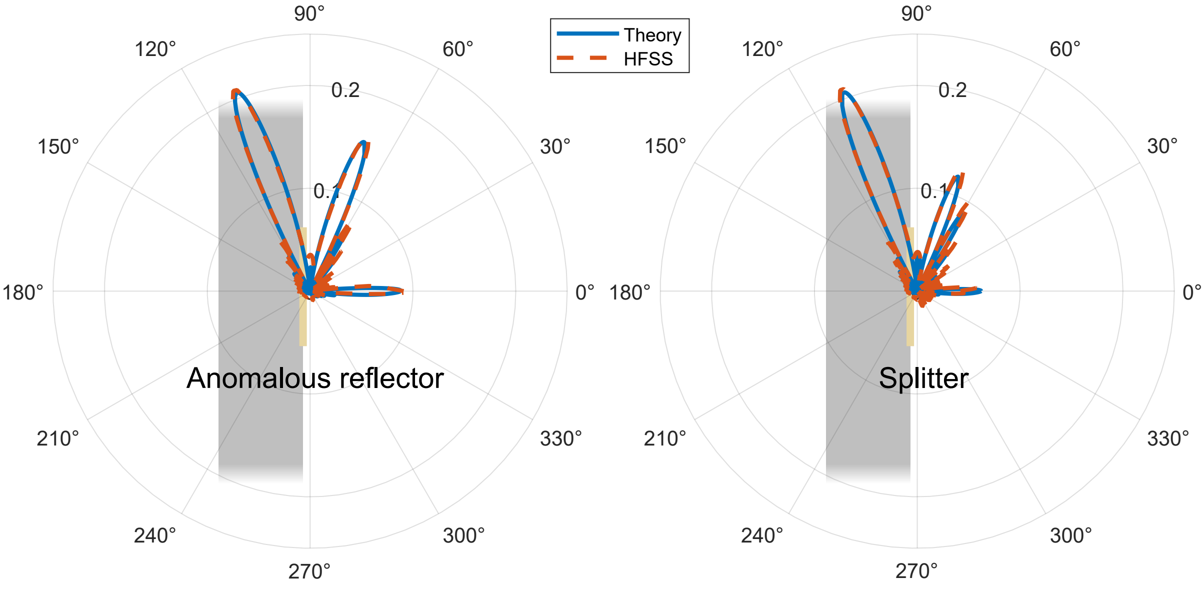
5. Find a surface where the input impedance is purely reactive for the desired set of waves and design the local surface reactance $X_s(x)$. This is the power flow-conformal solution, which does not need optimizations of spatial dispersion properties of the reflector.

In this presentation, we will show a modification of Method 2, where the effective impedance sheet is first discretized into a few step-wise uniform sections, before the optimization of its properties is made [2]. This approach removes performance degradation due to discretizations of the optimized continuously varying reactive sheet.

While the methods for design of periodical anomalous reflectors are well developed, making them reconfigurable is difficult, because the required angles of incidence and reflection define the array period. Scanning anomalous reflectors can be realized using the classical reflectarray approach, based on the use of $\lambda/2$-sized unit cells that can be tuned with various techniques. Unfortunately, these devices suffer from parasitic scattering, for the same reason as the periodical phase-gradient metasurfaces. Recently, it was shown that this deficiency can be overcome using reflectarrays formed by subwavelength unit cells [3, 4].

II. CONTROL OF SCATTERING FROM UNIFORM WALLS USING METASURAFACE PANELS

In future telecommunication systems working in the millimeter-wave band, mostly directive antennas will be used, e.g. [2]. When a reflection-shaping metasurface positioned at a wall is illuminated by a directive beam, also a portion of the uniform wall is illuminated, creating a specularly reflected beam. The beams reflected by the metasurface and the wall interfere, and care should be taken to estimate the total field at the receiver position [5]. Interestingly, metasurfaces can be configured as splitters to partially reflect also in the specular direction. Engineering the reflection phase of the wave reflected from the metasurface into specular direction, it becomes possible to partially control reflections also from the illuminated part of the uniform wall, although its surface is not modified.



(a) (b)

Fig. 1: (a): Scattering pattern for a finite-size perfectly conducting wall with a mounted anomalous reflector from 290° to the normal direction. The structure is illuminated by a plane wave at the angle of incidence 290°. (b): Scattering pattern for a finite-size wall with a mounted splitter. One half of the power incident on the splitter is reflected to 0°, and the other half is sent to the specular direction (70°) with zero reflection phase.

Figure 1(a) shows scattering pattern from a uniform wall with an anomalous reflector panel, with a strong beam reflected by the uniform wall into the specular direction (70°). Both the wall and the metasurface are of a square shape. The metasurface is mounted at the center of the wall, and it covers 1/4 of the wall surface. The large lobe on the left shows the shadow behind the wall. On Fig. 1(b), we see the pattern for the same wall when the metasurface reflects one half of the incident power into the specular direction with zero phase (as an artificial magnetic conductor). The other half is reflected to the normal direction (0°). We see that the total scattering into the specular direction is reduced, with significantly more scattering into side lobes, producing a diffuse scattering effect.

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